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METHODS FOR ESTIMATING FISH CATCH SIZES

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METHODS FOR ESTIMATING FISH CATCH SIZES

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16. ABSTRACT

This report reviews and evaluates methods for estimating fish catch size of major edible species in free-flowing rivers and nearshore marine areas. Based on this effort, a detailed work plan is presented for developing a stepwise regression analysis approach for estimating fish catch size.

A literature search was conducted and indicated that the methodology for estimating fish catch size is best developed for marine systems and worst developed for free-flowing rivers. The literature for marine water bodies contains a wealth of regression analysis and correlation efforts (including Box-Jenkins models) that relate one or more physicochemical factors (e.g., temperature, salinity, currents) to fish production or catch size for many species. The rather sparse literature on estimating fish catch size in free-flowing rivers emphasizes the possible usefulness of factors such as river length and water level fluctuation.

The stepwise regression analysis approach, which relates historical fish catch to corresponding environmental data, is described. This would provide EPA with guidance to develop a series of regressions for predicting fish catch size of different species in various locations.

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FOREWORD

The Exposure Assessment Group of EPA's Office of Research and Development has three main functions: (1) to conduct exposure assessments, (2) to review assessments and related documents, and (3) to develop guidelines for Agency exposure assessments. The activities under each of these functions are supported by and respond to the needs of the various EPA program offices. In relation to the third function, the Exposure Assessment Group sponsors projects for the purpose of developing or refining techniques used in exposure assessments. This study is one of these projects and was done for the Office of Water.

EPA must frequently assess the number of people exposed to a pollutant as a result of eating contaminated fish. This assessment can involve estimating the fish catch size in the area of interest. Since site-specific surveys on fish catch size are rarely available, the Agency needs alternative methods to estimate catch sizes. The purpose of this document is to provide a summary and evaluation of such methods.

James W. Falco, Director
Exposure Assessment Group

ABSTRACT

This report reviews and evaluates methods for estimating fish catch size of major edible species in free-flowing rivers and nearshore marine areas. Based on this effort, a detailed work plan is presented for developing a stepwise regression analysis approach for estimating fish catch size.

A literature search was conducted and indicated that the methodology for estimating fish catch size is best developed for marine systems and worst developed for free-flowing rivers. The literature for marine water bodies contains a wealth of regression analysis and correlation efforts (including Box-Jenkins models) that relate one or more physicochemical factors (e.g., temperature, salinity, currents) to fish production or catch size for many species. The rather sparse literature on estimating fish catch size in free-flowing rivers emphasizes the possible usefulness of factors such as river length and water level fluctuation.

The stepwise regression analysis approach, which relates historical fish catch data to corresponding environmental data, is described. This would provide EPA with sufficient guidance to develop a series of regressions for predicting fish catch size of different species in various localities.

CONTENTS

		Page
	FOREWORD	iii
	ABSTRACT	iv
	LIST OF TABLES	vi
	ACKNOWLEDGMENT	vii
I.	INTRODUCTION	1
II.	SUMMARY	1
III.	SURVEY AND REVIEW OF RELEVANT LITERATURE	4
	A. Literature Search Strategy	4
	B. General Characteristics of Fishing Effort and Stock Abundance Estimation	5
	C. Fish Catch Size Estimation in Impounded Rivers	12
	D. Fish Catch Size Estimation in Free-Flowing Rivers	18
	E. Fish Catch Size Estimation in Marine Waters	30
IV.	REGRESSION ANALYSIS WORK PLAN DEVELOPMENT	45
	A. Historical Use of Regression Analysis	45
	B. Regression Analysis Work Plan	46
	REFERENCES	52
	TECHNICAL REPORT DATA	61

LIST OF TABLES

		Page
1.	Selected Major Edible Finfish and Shellfish Species of the United States	2
2.	Selected Characteristics of Methods Widely Used To Monitor Fish and Shellfish Abundance	10
3.	Nine Regression Equations Developed by the National Reservoir Research Program for Estimating Angler Effort and Harvest	16
4.	Sport Fishery Catch Estimates	19
5.	Selected Correlations Between Water Level and Yield of Fish from the Danube River, Czechoslovakia (1960-74)	26
6.	Selected Studies Identifying the Relationship Between Environmental Factors and Fish Catch Estimation in Marine Waters	32
7.	The Relationship Between Sea Temperature and Commercial Catches of Selected Species at St. Andrews, New Brunswick, and Boothbay Harbor, Maine	36
8.	The Relationship Between Environmental and Marine Fish Parameters	38

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I. INTRODUCTION

Contamination of fish flesh by pollutants in water or by food chain magnification is a serious and pervasive phenomenon. The U.S. Environmental Protection Agency (EPA) must frequently evaluate the exposure of human populations to these pollutants as a result of eating contaminated fish. To evaluate such exposure, it is necessary to know the size of the exposed population, the levels of contaminants in fish flesh, and the patterns of human consumption of fish.

The exposed human population can be estimated from fish catch size and individual human fish consumption rates. To date, however, data on fish catch sizes have not been available in many areas to evaluate the extent of human exposure to fish contaminants.

The purpose of this report is to summarize the available information on non-field methods for estimating fish catch sizes for the common edible species in rivers and near-shore marine areas (Table 1) and to prepare a detailed work plan for refining an existing estimation method so as to achieve more accurate predictions.

II. SUMMARY

This report presents a review of the state of the art in estimating fish catch sizes for all water types with emphasis on rivers and near shore marine waters. In addition, a work plan is provided for the development of a fish catch size estimation method, which is more practical and better suited to areas of interest than the currently available methods.

Table 1. Selected Major Edible Finfish and Shellfish Species of the United States

A. Fish

Anchovy
Bass
Bluefish
Bluegill
Bonita
Buffalofish
Butterfish
Carp
Catfish (fresh and marine)
Cod
Crappie
Dolphin
Drum
Flounder
Grouper
Haddock
Hake
Halibut
Herring
Kingfish
Mackerel (jack and others)
Mullet
Perch (fresh and marine)
Pike
Pollock
Pompano
Rockfish
Sablefish
Salmon
Scup
Shark
Smelt
Snapper
Snook
Spot
Sunfish
Swordfish
Tilefish
Trout (fresh and marine)
Tuna (light and white albacore)
Whitefish

B. Mollusks

Abalone
Clam
Oyster
Scallop
Squid and Octopus

C. Arthropods

Crab (king and others)
Lobster (northern and spiny)
Shrimp

The first step in identifying the best available method of estimating river and marine fish catch sizes involved conducting a search of the major aquatic-related bibliographic databases using a carefully designed search strategy. This strategy, as well as a review of the major findings of the literature review effort, is presented in chapter III. The literature review indicates that fish catch estimation methodology is best developed in impounded rivers and is worst developed in free-flowing rivers. In marine systems, although there is a wealth of methodological literature, only a few categories of methods were found. None of the existing methods found for rivers or near shore marine areas, however, were deemed suitable without incorporating modifications. The most promising approach identified involves regression analysis using historical catch and environmental data. In chapter IV, the available data from all water types were used to formulate a detailed work plan for possible further development of fish catch estimation methods for marine and free-flowing riverine environments. The work plan involves regressing environmental factors against fish catch sizes and testing the predictability of the regression equations. The strategy considers a tradeoff between model simplicity and the increase in model accuracy of predictions as additional factors are considered.

III. SURVEY AND REVIEW OF RELEVANT LITERATURE

The purpose of this chapter is to present both the literature search strategy used (section A) and the major findings of the literature review on the estimation of fish catch sizes. A combination of computer database search and subsequent tree searching was used. The review of the relevant literature has been subdivided into several categories. In section B, fishing effort and stock abundance estimation are characterized to provide the reader with a perspective on the techniques used by fishery scientists in assessing important fish population parameters. The next three sections consider the approaches available for estimating fish catch size in impounded rivers (section C), in free-flowing rivers (section D), and in marine waters (section E). The most promising approach for all three involves regression analysis.

A. LITERATURE SEARCH STRATEGY

A comprehensive literature search for articles containing methods for estimating fish catch sizes was carried out in three phases:

- o Online Computer Search
- o Tree Search
- o Personal Contact

1. Online Computer Search

Four databases from the Lockheed Dialog Information System were accessed in the first phase of the literature search. A total of 201 recent citations were received for initial review: Aqualine (23), Aquatic Sciences and Fisheries Abstracts (69), National Technical Information Service (10), and Oceanic Abstracts (99).

The search strategy consisted of a logical manipulation of pertinent keywords:

Fish? + (Catch? or harvest? or trap? or stock? or yield?) + (Estimate? or survey?) + (Model? or technique? or procedure? or method?)---where *? is the symbol for truncation.

In databases where retrieval was very high (over several hundred citations), the parameter of the search was further limited by searching only titles and keywords or descriptions. In addition, hard copies of Aquatic Sciences and Fisheries Abstracts (1971-78) were manually searched, since they had not been computerized.

2. Tree Search

On completion of the online computer search, the resulting printouts (titles and abstracts) were reviewed and screened for relevancy. Relevant articles were retrieved and critically reviewed. Additional material was then selected from the bibliographies of selected articles.

3. Personal Contact

The third phase of the literature search consisted of seeking the advice of scientists knowledgeable in methods of estimating fish catch size. Four investigators who were particularly helpful were Robert Jenkins of the U.S. Fish and Wildlife Service (FWS); B. G. Thompson, Chief of the Resource Statistics Division of the National Marine Fisheries Service (NMFS); Robert Hutton of NMFS; and R. T. Oglesby of Cornell University.

B. GENERAL CHARACTERISTICS OF FISHING EFFORT AND STOCK ABUNDANCE ESTIMATION

It was clear from the literature search that there are two key parameters that affect estimation of fish catch sizes: (1) estimation of the efficiency of fishing effort, and (2) estimation of the size of the fish stock available. A brief discussion of the various techniques including some field approaches that are used to characterize fishing effort and stock abundance is given below.

1. Fishing Effort

Although it is not the purpose of this task to provide an extensive review of fishing effort or catch per unit effort (see Saville, 1977; Ricker, 1975), some evaluation of these parameters is necessary because they greatly impinge on catch size estimation. "Fishing effort" has several meanings to fishery biologists, including a representation of the total amount of time, money, labor, technology, and/or skill used in catching fish. It also represents the statistics of effort that permit measurement of the (1) proportion of fish being caught, (2) relative abundance of fishing mortality, and (3) catch per boat. In general, fishing effort depends on the kind of fishing gear and vessel used, the efficiency of the gear, and the vulnerability of the stock during fishing.

The Fish and Wildlife Service of the Department of the Interior has estimated that a total of 36 million people fished in United States waters during 1980. Of these people about 20 percent (7.2 million) fished in streams and rivers and 33 percent (12 million) fished in surf, coastal, and nearshore waters (Robert Jenkins, written communication).

Catch per unit effort has long been the key element used to evaluate a particular fish population and to predict changes in the population over several years. One unit of fishing effort removes a constant proportion of the remaining stock and is directly related to fishing mortality by a catchability coefficient (i.e., the proportion of a fish stock caught by a defined unit of effort). Thus the catch is considered in terms of a particular boat fishing for a known time and using a particular type of gear, although the actual fish landings depend on many factors. However, using fishing effort to measure fishing mortality or catch per unit effort to indicate abundance is not particularly straightforward for at least two reasons. First, the catchability coefficient is not a constant because both fish and fishermen are not randomly distributed for each water body or over time. Second, a good index of fishing effort is a function of the factors mentioned above; i.e., gear type, vessel type, gear efficiency, and stock vulnerability (Ricker, 1975).

2. Stock Abundance

The concept of stock abundance (i.e., the proportion of a fish population that is actually or potentially usable) is also germane to fish catch size estimation. A number of techniques are outlined below that give estimates of stock abundance in free-flowing rivers and in marine waters. These provide a perspective of how fishery scientists assess catches, biomass, and other fish population statistics. Some of the approaches used in the two environments are similar, but key differences among the methods are given regarding their applicability, species discrimination ability, cost, and other factors.

a. Rivers

There are three broad approaches used to assess fish stock abundance in rivers. The approaches use commercial catch (or other catch) data, experimental surveys, or environmental factors correlated with catch (or other statistical) data. The applicability of each approach is influenced by the nature of the river (e.g., its productivity and physical structure), the particular fish stocks involved, and the availability of the appropriate biological statistics and historical catch data.

The first approach, using commercial or other catch data, would seem to be the most cost effective, since the data already may have been gathered by State or Federal agencies for another purpose. Although there are several problems with this approach, the main difficulty is that commercial catch data are usually not available for any rivers, other than the very large ones. Another problem is that an approach based on commercial catch data requires additional information, which is not always available. This reduces the general utility of the approach. For example, Backiel (1971) devised a method that utilized catch data but which also required the use of data on production, biomass, and mortality. Another example is the biostatistical approach (see Ricker,

1975) for using commercial data. The commercial catch data, again, had to be supplemented with mortality estimates to enhance the utility of the method.

Where commercial data are not found, other estimated catch values may be available. For example, some researchers and State agencies publish sport catch data (e.g., creel surveys). These data provide a base for possible regression analyses using environmental data (see chapter IV).

Numerous experimental surveys have been used to assess fish stocks. These include area-catch methods for eggs, larvae, juveniles, and adults; catch-effort methods; mark-recapture methods (using tags); and others. Perhaps the most widely used method of assessing fish stock abundance in rivers utilizes a combination of area-catch and catch-effort methods. A closed section of the river is surveyed, and the decline in catch per unit effort is recorded during successive fishing efforts (Leslie and Davis, 1939; DeLury, 1947). Examples using this approach and a critique of it were given by Ricker (1975).

Problems with catch-effort methods often originate with the assumption that the probability of catching one fish is constant. In rivers, as in other aquatic habitats, catchability varies with species, fish size, fishing method, and environmental conditions (Ricker, 1975; Mahon, 1980).

In addition to the use of commercial catch data and experimental survey methods, a third approach, which correlates catch (and other) statistics with particular environmental factors, has been used to assess fish stocks in rivers (Holcik, 1979; Welcomme, 1976). The approach has been reported for rivers in Europe and Africa, but studies for rivers in North America were not found. In Europe, fish yields have been predicted using one or more environmental factors such as river width, water level, alkalinity, and temperature, as well as other factors such as

productivity indices (Huet, 1964; Lassleben, 1977; Holcik, 1979). In Africa, yields have been predicted from river length and basin size (Welcomme, 1976).

The general approach of predicting fish yields in rivers from environmental factors is discussed further in section D and chapter IV.

b. Marine

Six approaches have been identified for monitoring marine fish and shellfish abundance:

- Catch/effort statistics from commercial fisheries
- Fishing surveys (e.g., trawling, seining, gill netting, longlining, trapping, poisoning, and electroshocking)
- Acoustic surveys
- Visual surveys from shore, boat, or plane
- Egg/larvae surveys
- Tagging.

The major advantages and disadvantages of each approach have been reviewed elsewhere (Ulltang, 1977; Ricker, 1975). Table 2 summarizes each of the methods with respect to: (1) applicability to different stocks; (2) ability to discriminate among species; (3) the variance and bias in the results; (4) equipment requirements; (5) cost; and (6) time required to process data. The first two approaches, however, are felt to be preferable to the others for obtaining abundance data.

The major advantages of using commercial fishery data are: (1) they are inexpensive, since the data may have already been collected for other purposes, and (2) the sample variance may be small (Saville, 1977). It should be cautioned that drastic changes in vessels, gear, and method of operation make the use of previous catch/effort relationships more difficult (Ulltang 1977). Another disadvantage is that sport catch data are not obtainable from commercial data.

Table 2. Selected Characteristics of Methods Widely Used To Monitor Fish and Shellfish Abundance[a]

Method	Applicability	Discrimination Between Species	Result		Craft and Equipment	Cost	Time To Process Data
			Variance	Possible Bias			
Commercial catch/ effort statistics	Demersal and pelagic[b]	Excellent	Variable	Large	Problems with changes in vessels and fishing gear; no sport catch data	Low[c]	Moderate
Fishing survey	Demersal and pelagic	Excellent	Large	Small	Vessel and fishing gear	High	Moderate
Acoustic survey	Pelagic	Poor	Small	Large	Vessel and acoustic gear	Low[d]	Short
Visual survey	Pelagic	Poor	Large	Large	Aircraft or boat	Variable	Short
Egg/larvae survey	Demersal and pelagic	Excellent[e]	Large	Large	Vessel and collector	High	Long (laboratory)
Tagging	Demersal and pelagic	Excellent	Variable	Large	Vessel and gear for releasing and for catching	Variable	Moderate

[a]Source: Ulltang (1977).

[b]Bottom - feeders and open water - feeders, respectively.

[c]Cost may be low because data may already have been gathered for another purpose.

[d]Excluding the high cost of acoustic equipment.

[e]Excluding problems in distinguishing different species' eggs.

The other five approaches require extensive field work and, therefore, are less relevant to this report but are presented briefly for sake of completeness.

The predominant commercial fishing survey method in many situations is trawling. A change in trawling catch size (when fishing intensity exceeds a minimum level) generally indicates a change in population numbers. Changes in trawl catch sizes have been generally interpreted to indicate annual changes in fish stocks. Variation in fish catches within any single year, however, results from changes in the annual climatological cycle rather than from fluctuations in actual numbers. Commercial fishing effort itself reflects this, being frequently limited to selected portions of the annual population cycle (e.g., migration and spawning). Thus, any phenomenon that affects the seasonal cycle may markedly affect the catch.

The primary disadvantage of fishing surveys is their large sampling error, which necessitates a large number of samples (at high cost) to improve the precision of the method (Saville, 1977). Because specialized surveys can provide information on larval and immature organisms (in contrast with commercial data), these surveys may be useful in predictions about future stocks. Ulltang (1977) pointed out that surveys can be used in principle to predict catch rates in new fisheries, whereas in reality the variables are more complex.

Acoustic surveys have been widely studied and seem to have the greatest advantage for pelagic populations of fish that school at middepths (Cushing, 1973; Ulltang, 1977). The ability of acoustic methods to discriminate among species is poor and must be supplemented by other sampling methods. Acoustic surveys, when made under favorable circumstances, have been shown to be more precise than other methods.

Visual surveys have few advantages relative to other methods except for species of large fish showing strong schooling behavior at the sea surface (Ulltang, 1977).

Egg/larvae surveys generally suffer from variable and biased results, as well as high costs and lengthy laboratory analyses, which combine to make the method not very useful in stock assessment (Ulltang, 1977).

Tagging and experimental fishing to recapture the tags may be the best way to estimate the absolute abundance of a fish species that is not exploited commercially and one that is not a good prospect for an acoustic survey (Ulltang, 1977). The cost, however, will be high unless the stock is few in number and found in a limited geographical area.

C. FISH CATCH SIZE ESTIMATION IN IMPOUNDED RIVERS

Fish catch size estimation methods have been far more extensively studied in impounded rivers (i.e., reservoirs) than in free-flowing rivers. The works of Jenkins (1968; 1974) and Ryder (1965; 1982) are particularly appropriate to this review. Both of these investigators have developed approaches using regression analyses or simple indices that successfully predict fish yields based on a few environmental factors. The historical development of their approaches is summarized below because of the perspective provided and the potential for contribution to the development of similar prediction methods for fish catches in rivers and marine waters.

Numerous morphometric (i.e., basin shape), edaphic (soil), and other environmental factors have long been recognized to affect fish production and catches in impounded rivers and natural lakes. Rawson (1952) first demonstrated the existence of an inverse relationship between fish production and mean depth based on a study of some Canadian lakes. Northcote and Larkin (1956) found that total dissolved solids was the best indicator of lake productivity in their study of 100 lakes in British Columbia. In some Minnesota lakes, Moyle (1956) correlated fish

production with water chemistry (phosphorous levels in particular). Ryder (1965), recognizing the importance of these and other studies, developed the morphoedaphic index (MEI):

$$MEI = \frac{\text{total dissolved solids}}{\text{mean depth}}$$

and showed that the index was related to total fish catches in 23 large North American lakes. The MEI has been widely applied as a fish catch estimator with divergent results (e.g., Jenkins, 1968; Henderson and Welcomme, 1974; Oglesby, 1977; Matuszek, 1978; Schlesinger and Regier, 1982). The overall simplicity of the index has been the basis of much praise and criticism. The MEI has often proved to be a quick and valuable predictor of fish yield, but where data failed to fit the model, the model was criticized as being an artifact, too simplistic, or theoretically unsatisfying. Many criticisms remain in the current literature, although the model was conceptually expanded by Ryder et al. (1974) and Ryder (1978), with the original results (i.e., Ryder, 1965) having been duplicated by Matuszek (1978).

Two of the original objectives of the MEI were: (1) to determine the empirical relationship between fish yield and two abiotic factors, and (2) to provide a simple technique for estimating annual yield. In general, the model will fail to predict accurately when: (1) Ryder's (1965) original criteria are misapplied; (2) the group of lakes is not homogeneous; (3) inappropriate data are used; or (4) appropriate distinctions are not made among global, regional, and infraregional models (Ryder, 1982).

Ryder (1982) suggested that large variances in the regression of the fish yield on MEI indicate that some criterion for the use of the model has been violated. For example, consideration of a single turbid lake with a group of clear lakes violates the homogeneous lake criterion. In this example, the turbid lake should be evaluated with a separate group

of turbid lakes. Other important characteristics contributing to a homogeneous set of lakes suitable for regression analysis might include: (1) reasonably constant ion ratios, (2) at least a moderately intensive fishing effort on the most abundant species for some years, and (3) ratios of flushing time to lake volume (these ratios are often constant within a group of lakes).

The most important thing to recognize in using Ryder's index is that many environmental factors are going to influence fish production to some degree. The problem of estimating fish production would become intractable if all the numerous variables and their interactions were considered in deriving the index. It is therefore desirable to concentrate on those few factors known to be the best indicators of fish production.

Ryder (1982) stated that the fundamental concept in any morphoedaphic expression is that externally supplied energy and matter in any aquatic system will be "channeled, cascaded, dissipated, or retained" within the system as a function of its morphology. The input of energy and matter into a water body is regulated and constrained by the general structure of the basin and determines the biotic output and the production of fish and other organisms. Solar energy, in conjunction with nutrients and other matter, determines the primary production (plants) of a system that may be cycled into higher trophic levels. The shape of the basin contributes to the channeling, dilution, and eventual dissipation of energy and matter and thus serves as a sink for energy and nutrients (Ryder, 1978).

Ryder (1965) indicated that total dissolved solids (TDS) and mean depth were the best indicators of fish yield in his original North American model. These two factors have also been explored by Robert Jenkins of FWS. Jenkins (1968) reported that TDS was the best correlate for predicting total standing crop of fishes in large U.S. reservoirs,

and mean depth was the best correlate for commercial fish harvest in them. The relationship between sport harvest (y) and log MEI (x) in 121 reservoirs was: $y = 0.88 + 0.183 x$ ($r = 0.23$; $P = 0.02$). For commercial harvests (y) and log MEI (x) in 46 reservoirs, the relationship was $y = 0.52 + 0.221 x$ ($r = 0.21$; $P < 0.05$). (NOTE: r ranges from -1.0, perfect inverse correlation, to +1.0, perfect direct correlation. Thus, these regressions do not indicate particularly good prediction but have the advantage of simplicity and a limited number of independent variables.)

Jenkins and coworkers, of FWS's National Reservoir Research Program, developed additional model regressions that related other selected environmental factors to fish harvests and standing crops in U.S. reservoirs. The methods and relationships among variables were discussed by Jenkins (1968; 1974; 1976) and Jenkins and Morais (1971). A large number of regressions that had been applied to U.S. reservoirs exceeding 500 acres at normal pool level were published by FWS (1981). Nine of these regressions are given in Table 3.

In many lakes, phosphorus is the limiting nutrient and has been suggested to be an appropriate correlate of TDS by Ryder (1982), particularly the total phosphorus concentrations at spring turnover (just prior to initiation of summer stratification). Other TDS correlates have been proposed, but they offer little improvement on the original model. Consideration of climatological factors, however, has enhanced interpretation of the model.

In Ryder's model (Catch = 2.3 $[MEI]^{0.441}$), climate was considered to be homogeneous for the group of lakes. To permit global integration of various regional models, some climatic factor (incorporating altitudinal and latitudinal effects) was proposed to be necessary (Ryder et al., 1974; Ryder, 1978). The length of growing season or some related temperature effect was suggested. Henderson and Welcomme (1974) developed a regression for large African lakes (Catch = 14.4 $[MEI]^{0.468}$). Although the slopes of the two regressions are quite similar, the

Table 3. Nine Regression Equations Developed by the National Reservoir Research Program for Estimating Angler Effort and Harvest[a]

1. Total annual sport fish harvest (pounds per acre) in all reservoir types.

   log (sport fish harvest) = -0.8104 - 0.2266 log (AR) + 0.2090 log (DS) + 1.1432 log (GS) - 0.2713 log (AG)

   n = 103 r^2 = 0.22 (r = 0.47)

2. Total pounds (not pounds per acre) of sport fish harvested annually in all reservoir types.

   log (sport fish harvest) = 1.811 + 0.7866 log (AR)

   n = 208 r^2 = 0.53 (r = 0.73)

3. Total annual sport fish harvest (pounds per acre) in selected reservoir types.

   log (sport fish harvest) = -0.3892 - 0.1519 log (AR) + 0.2027 log (DS) + 0.9796 log (GS) - 0.3055 log (AG)

   n = 46 r^2 = 0.69 (r = 0.83)

4. Annual black bass harvest (pounds per acre) in all reservoir types.

   log (bass harvest) = -5.8541 - 0.08691 log (AR) + 2.9994 log (GS) - 0.3336 log (AG)

   n = 103 r^2 = 0.29 (r = 0.54)

5. Annual sunfish harvest (pounds per acre) in all reservoir types.

   log (sunfish harvest) = -4.2043 - 0.4669 log (AR) + 2.957 log (GS) - 0.6178 log (AG)

   n = 103 r^2 = 0.45 (r = 0.67)

6. Annual sport fish harvest (number of fish per acre) in all reservoir types.

   log (sport fish number) = 0.2894 - 0.3437 log (AR) + 1.2296 log (GS) - 0.3761 log (AG)

   n = 103 r^2 = 0.28 (r = 0.53)

7. Annual sport fish harvest rate in terms of pounds harvested per angler-hour of effort in all reservoir types.

   log (pounds/angler-hour) = -0.8811 + 0.1851 log (AR) - 0.0812 log (SR) - 0.0957 log (AG) - 0.1207 log (DF)

   n = 168 r^2 = 0.28 (r = 0.53)

8. Total annual angler effort (days per acre) in all reservoir types.

   log (annual angler days per acre) = -3.3925 + 0.9473 log (AR) - 0.1729 (log [AR])^2 + 0.2387 log (DS) + 1.1936 log (GS)

   n = 103 r^2 = 0.32 (r = 0.57)

9. Annual commercial fish harvest (pounds per acre) in all reservoir types.

   log (commercial harvest) = 6.4819 - 0.492 log (MD) - 0.231 log (DF) - 0.204 log (SR) - 2.453 log (GS) + 0.482 log (AG)

   n = 45 r^2 = 0.48 (r = 0.69)

[a] Adapted from: U.S. Fish and Wildlife (1981).

ABBREVIATIONS: AG (reservoir age in years), AR (reservoir area in acres), DF (mean annual vertical fluctuation in feet), DS (dissolved solids), GS (growing season in days), MD (mean depth in feet), and SR (storage ratio).

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predicted catches are substantially greater for the African lakes, possibly verifying the need to incorporate a climatic factor. Jenkins (1967) found that by incorporating growing season length into his otherwise most significant multiple regression, there was a substantial increase in the percent variability explained for the U.S. reservoir commercial and sport harvests.

In another recent study, a climatic factor was also incorporated into a fish yield regression and accounted for substantially more variability than did the MEI alone. Schlesinger and Regier (1982) quantified the relationships among climate, estimates of fish yield, total dissolved solids, and mean depth for natural lakes situated between 15° S. latitude and 62° N. Using 43 lakes supporting recreational and commercial fisheries, stepwise regression analyses indicated that the mean annual air temperature accounted for 74 percent of the variability in their fish yield factor (maximum sustainable yield). The MEI alone accounted for less than 10 percent of the variability.

In summarizing the overall use and abuse of the morphoedaphic index, Ryder (1982) suggested that a rational approach to fish yield estimation may be made at three hierarchical levels. At the highest or global level, temperature and lake surface area are key factors. They are considered global because their total range generally exceeds their individual ranges in any region. At the middle or regional level, Ryder considered mean annual temperature to be generally constant. Variations in nutrient input and morphometry, which govern nutrient and energy movements, assume key importance. This explains the utility of the MEI at the regional level. The third or infraregional level includes a very similar group of lakes (e.g., in the same watershed). At this level, either the numerator or denominator of the MEI may be quite similar for all the lakes considered and can be omitted from a multiple regression.

D. FISH CATCH SIZE ESTIMATION IN FREE-FLOWING RIVERS

Relatively few studies were found for estimating fish catch size in free-flowing rivers, in contrast with the extensive literature available for lakes or impounded rivers. Sport catch estimates for a number of species from selected rivers are given in Table 4. One reason is that river sampling methods are generally less adequate than lake sampling methods (Holcik, 1979). Another reason for the lack of data on free-flowing rivers is that in many regions they are of less interest to fishermen than lakes and reservoirs (Hynes, 1970). A third reason is that most rivers are less stable than lakes; environmental conditions, such as water temperature and water chemistry, usually change more rapidly in rivers. Fish populations in rivers can be expected to respond more rapidly as well. Hence, the solitary discharge of a pollutant, which may cause a fish kill or high tissue levels of a chemical, may never be chemically detected, having moved downstream beyond detection before the biologic response was observed.

Nevertheless, some catch size estimation approaches have been developed but are comparatively subjective (Backiel, 1971; Huet, 1964; Lassleben, 1977). Other approaches have been applied to certain rivers; e.g., those with extensive and frequently unaltered flood plains (Holcik, 1979; Welcomme, 1976). These approaches are untested for essentially all North American rivers. The methods presented here for fish catch estimation have been selected because of their relative simplicity and practicality. The methods were chosen for potential applicability using important characteristics of rivers such as current velocity, bank and bottom types, obstacles to flow, and the variety of uses of the river by man. As with any fish estimation method, gear efficiency and selectivity are also important but have been reviewed elsewhere (Ricker, 1975).

1. Area-Catch Methods

Several approaches for fish catch prediction can be grouped under the heading of area-catch methods. They are based on the assumption that

Table 4. Sport Fishery Catch Estimates

Species	Location	Comment	Reference
RIVERS			
Brown Trout	Au Sable River (New York)	Creel census of 2 stream sections 1974 - 1976: 60 and 113 lb/acre	Alexander et al. (1979)
Brown Trout	Chattahoochie River (Georgia)	Creel census of 70 km section from March 1977-Feb 1979: about 1,000 kg	Hess and Ober (1980)
Brown Trout	Madison and Firehole Rivers (Wyoming)	Creel census of 12 mi sections in 1969 yielded 2,400 and 1,550 fish, respectively	Erman (1972)
Rainbow Trout	Chattahoochie River (Georgia)	Creel census of 70 km section from March 1977-Feb 1979; about 6,800 kg	Hess and Ober (1980)
Rainbow Trout	Madison and Firehole Rivers (Wyoming)	Creel census of 12 mi sections in 1969 yielded 460 and 2,380 fish, respectively	Erman (1972)
Brook Trout	Au Sable River (New York)	Creel census of 2 stream sections 1974 - 1976: 18 and 24 lb/acre	Alexander et al. (1979)
Brook Trout	Chattahoochie River (Georgia)	Creel census of 70 km sections from March 1977-Feb 1979: about 1,800 kg	Hess and Ober (1980)
Steelhead	Santian River (Oregon)	Creel census on 16 km section from Mar-Oct 1978: 2,466 ± 440 (95 percent confidence interval); 52,000 angler hours	Buchanan et al. (1979)
Steelhead	North Fork of Stillaguamish River (Washington)	Road check creel census, 1962 - 1964: about 4,500 fish/year	Southward and Douglas (1972)
Chinook Salmon	Elk River (Oregon)	Creel census of lower section (6 km) in 1974: about 2,500 fish	Bender and McGie (1978)
Chinook Salmon	South Sandy Creek (New York)	Creel census of 6.75 mile section in fall, 1976; 3,266 anglers fished 9,066 hours and caught 5,257 fish	Farr and Blake (1979)
Salmon	Cowlitz River Lower Columbia River Chehalis River (Washington)	19,798 annual 14,790 sport catches 2,851 in 1977	Hoines et al. (1978)

Table 4. Sport Fishery Catch Estimates (Continued)

Species	Location	Comment	Reference
RIVERS (continued)			
Suckers	Flint River (Georgia)	Creel census of 124 km section July 1974 - June 1975: 12,400 kg	Hess and Ober (1980)
Paddlefish	Neosho River (Oklahoma)	Creel census of 10 km section 1979-1980: 6,015 fish (114,000 kg)	Combs (1982)
Catfish and Bullheads	Flint River (Georgia)	Creel census of 124 km section July 1974 - June 1975: 20,700 kg	Hess and Ober (1980)
Channel Catfish	Platte River (Missouri)	Creel census of 57 mile section 1970-1971: 11,436 fish	Flenner (1973)
Flathead Catfish	Platte River (Missouri)	Creel census of 57 mile section 1970-1971: 5,605 fish	Flenner (1973)
Sunfish	Flint River (Georgia)	Creel census of 124 km section July 1974 - June 1975: 5,700 kg	Hess and Ober (1980)
"Bass"	Flint River (Georgia)	Creel census of 124 km section July 1974 - June 1975: 8,100 kg	Hess and Ober (1980)
Rock Bass	Big Piney River (Missouri)	Creel census of 45 mile section 1963-1972: 7.0 lb/acre	Flenner (1973)
Smallmouth Bass	Big Piney River (Missouri)	Creel census of 45 mile section 1963-1972: 2.7 lb/acre	Flenner (1973)
Sunfish	Big Piney River (Missouri)	Creel census of 45 mile section 1963-1972: 2.5 lb/acre	Flenner (1973)
Carp	Platte River (Missouri)	Creel census of 57 mile section 1970-1971: 10,566 fish	Flenner (1973)
ESTUARIES			
White Sturgeon	Sacramento-San Joaquin Rivers (California)	Annual catch 327 fish (mean weight 12-18 kg)	Kohlhorst (1980)
Striped Bass	San Pablo Bay (California)	Partyboat harvest in 1968 2,600 fish (mean weight 9.4 lb); 3,300 angler days.	McKechnie and Miller (1971)

Table 4. Sport Fishery Catch Estimates (Continued)

Species	Region	Comment	Reference
MARINE			
Blue Marlin	Atlantic Coast and Gulf of Mexico (USA)	Combined tournament and charterboat catches in 1978 = 1052 fish	Beardsley and Conser (1980)
White Marlin	Atlantic Coast and Gulf of Mexico (USA)	Combined tournament and charterboat catches in 1978 = 1394 fish	Beardsley and Conser (1980)
Sailfish	Atlantic Coast and Gulf of Mexico (USA)	Combined tournament and charterboat catches in 1978 = 1952 fish	Beardsley and Conser (1980)
Red Drum	Galveston Bay (Texas)	Sept-Oct 1981. Creel census at 6 piers during spawning; 8584 fisherman caught 275 fish (1895 kg) catch rate <0.01 fish/man-hour	Weixelman (1982)
Red Snapper	Coastline (Texas)	Charter boat harvest (Sept 1980-Aug 1981) = 254,000 fish	McEachron (1983)
Amberjack	Coastline (North Carolina)	Charter boat harvest in 1977 Northern 19,000 lb Central 67,000 lb Southern 23,000 lb	Manooch and Laws (1979)
Bluefish	Coastline (North Carolina)	Charter boat harvest in 1977 Northern 121,000 lb Central 89,000 lb Southern 34,000 lb	Manooch and Laws (1979)
Bluefish	Coastline (Alabama)	Recreational harvest in 1975 910,000 lb	Wade (1977)
Sea Trout	Coastline (Alabama)	Recreational harvest in 1975 800,000 lb	Wade (1977)
Sea Trout	Coastline (Texas)	Headboat harvest (± SE) in 2 Bay systems: Galveston = 40,555 (9387) fish Aransas/Corpus Christi = 54,073 (12,515)	McEachron and Matlock (1983)

Table 4. Sport Fishery Catch Estimates (Concluded)

Species	Region	Comment	Reference
MARINE (continued)			
Kingfish	Coastline (Texas)	Headboat harvest (±SE) in 2 Bay systems: Galveston = 2,004 (391) fish Aransas/Corpus Christi = 2,672 (521)	McEachron and Matlock (1983)
Kingfish	Coastline (South Carolina)	Harvest from 12 piers Apr-Nov 1974; 150,961 fish (38,000 lb)	Hammond and Cupka (1977)
Spot	Coastline (South Carolina)	Harvest from 12 piers Apr-Nov 1974; 332,206 fish (91,000 lb)	Hammond and Cupka (1977)
Croaker	Coastline (South Carolina)	Harvest from 12 piers Apr-Nov 1974; 246,497 fish (54,000 lb)	Hammond and Cupka (1977)
Croaker	Coastline (Texas)	Headboat harvest (±SE) in 2 Bay systems: Galveston = 17,914 (5,244) fish Aransas/Corpus Christi = 794 (301)	McEachron and Matlock (1983)
King Mackerel	Coastline (Alabama)	Recreational harvest in 1975 1,050,000 lb	Wade (1977)
King Mackerel	Bay County (Florida)	Recreational harvest (boats) in 1975 222,000 fish (1,100,000 lb) from 116,000 angler hours; based on questionnaires and logbooks	Brusher, et al. (1976)
King Mackerel	Coastline (North Carolina)	Charter boat harvest in 1977 Northern 315,000 lb Central 191,000 lb Southern 231,000 lb	Manooch and Laws (1979)
King Mackerel	St. Andrews Bay (Florida)	Charter boat harvest in 1973 74 percent of harvests were King Mackerel - average catch rates 0-32.0 fish/hour	Sutherland (1977)

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the number of fish caught in a known area of a river is related to the area of some larger segment of that river. The first area-catch method considered here is derived from fish catch data and is widely used in oceans (Nikolskii, 1969) but has also been applied to rivers (Holcik, 1979). By this method, population estimates are said to vary as a direct function of the number of fish sampled and total river area, and as an indirect function of the percentage of river area sampled. Holcik stated that the main difficulties of the method come from defining the gear efficiency, which itself depends on the type of species, its size and condition, when fishing occurred, many climatological conditions, and other factors.

A second area-catch method is embodied in those studies using a catch-effort approach. This approach has been used widely for lakes and oceans (see Ricker 1975). The relative abundance, and indirectly the number of fish, may be measured by an index consisting of total fish catch (for the river or a segment) divided by total fishing intensity (using all gear types), where the fishing intensity of the gear is the product of fishing effort and length of time fished. It is sufficient to say that estimates of fishing effort are often rather imprecise and subject to large variability of the estimates.

A third area-catch method is the two-catch approach (Seber and Le Cren, 1967). In this approach, the population size (N) is estimated from successive catches (C_1 and C_2), each taken with equivalent effort,

where:

$N = (C_1)^2/(C_1 - C_2)$ and

the variance $= (C_1)^2 \times (C_2) \times (C_1 + C_2)^2 \times (C_1 - C_2)^4$.

The success of the method depends on at least four conditions being met: (1) the ratio $(C_1 - C_2)/C_1$ must be large enough to have a substantial effect on the population size; (2) this ratio must be constant, indicating the fishing effort for both catches was the same and that the fish remaining in the river are as susceptible to being caught as the fish caught first; (3) mortality, recruitment, and migration are assumed to be zero between the two catches; and (4) fish caught on the first catch cannot enter into the count of the second catch.

The area-catch methods briefly discussed above were not developed primarily for estimating fish catch sizes. Hence, although they are pertinent to stock abundance assessment, they do not provide the ideal basis for development of catch size estimation methods.

2. The Relationship of Fish Population Parameters to Catch Data

In contrast to the three area-catch methods, another approach is applicable where commercial fisheries already exist; the approach is based on an estimation of fish stocks using both the catch data and the fish population estimates. Two methods using this approach have been tested for rivers, one proposed by Backiel (1971) and another proposed by Huet (1964) and further developed by Lassleben (1977). Backiel used the relationship between annual catch (C), biomass lost by natural mortality (M), and production/biomass (P/B) ratio as follows: (production) $P = (C + M)/(P/B)$. Holcik (1979) suggested that certain assumptions may be applicable where natural mortality and the P/B ratio are not known: (1) catch and natural mortality are of the same order of magnitude, and total mortality is equal to $C + M$; (2) mortality is balanced by recruitment and growth; and (3) the P/B ratio ranges from about 0.5 to 1.0. The first two assumptions are commonly used in practice (Holcik, 1979); the third assumption is supported by Huet (1964), Mann (1965), and Backiel (1971).

Huet (1964) suggested that stream fish productivity (kilograms of fish per kilometers of river length) may be estimated from the product of three factors: "biogenic capacity" (B), river width (W) (in meters), and

coefficient of productivity (K). Values of B are subjective: 1-3 indicate little food available for fish; 4-6 indicate average food available; 7-10 indicate ample food available. Values of K are the product of annual average temperature, water acidity, and type of fish population. Experimental changes of Huet's method by Lassleben (1977) involved additional considerations, making the method even more subjective and less practical than it was when first described.

The above methods primarily contribute information on stock assessment and only secondarily on estimating catch size. Although there are methods that have been concerned primarily with estimating catch size, the techniques, in general, have not been applied to rivers. Moreover, they often rely on fish population statistics that are not available or are cumbersome to use. The most practical and simple approach is based on correlations between previous catches and certain environmental factors, especially hydrological parameters (Holcik, 1979).

3. Correlation of Catch Data with Physical Factors

The correlation of existing fish catch data with selected physical factors offers the most promising approach towards meeting the goal of estimating fish catch sizes in rivers. Successful application of the approach requires the availability of appropriate historical fish catch and physical environmental data from the same region.

The relationship between total fish yield (i.e., catch) and water level fluctuation in the Danube River has been described by Holcik (1979) and Holcik and Bastl (1977). For the years 1960-74, Holcik and Bastl developed a series of 14 regressions. Five of these were significant ($P < 0.02$) and are given in Table 5. High correlations (r is greater than 0.9 or less than -0.9) were found between: (1) total annual fish yield in low water years and mean water level in the corresponding low water years; (2) total annual fish yield for high water years and mean water level for the preceding high water years; and (3) total annual fish yield for years preceded by high water and the mean water level for preceding years.

Table 5. Selected Correlations Between Water Level (x) and Yield of Fish (y) from the Danube River, Czechoslovakia (1960-74)[a]

Equation	Yield (metric tons)	Water Level (cm)	Correlation Coefficient (r)	Student's t	Level of Significance	Data Pairs
(1) $y = 55.5 + 0.467\ x$	Total annual yield	Mean annual water level for year of catch	-0.76	3.68	<0.01	12
(2) $y = 276.5 - 0.307\ x$	Total annual yield for low water years	Mean annual water level for low water years	-0.96	5.72	<0.02	5
(3) $\log y = -0.767 + 1.21 \log x$	Total annual yield for high water years	Mean annual water level for preceding high water years	0.95	5.17	<0.02	5
(4) $y = 39.6 + 0.386\ x$	Total annual yield	Mean maximum water level for year of catch	0.71	3.22	<0.01	13
(5) $y = -93.2 + 0.838\ x$	Total annual yield for years preceded by high water	Mean annual water level for preceding years	0.93	5.73	<0.01	7

[a] Source: Holcik and Bastl, 1977.

Holcik and Bastl (1977) cautioned that yields were affected not only by water level but also by fishing effort. They observed only two negative correlations out of the total of 14 relationships tested, two of the correlations being between yield and water levels in low water years. Apparently, fishing effort was increased at times of low water, probably due to greater fisherman accessibility, longer fish harvest periods, and the use of different gear types.

Holcik and Bastl (1977) suggested an ecological mechanism to explain the relationships found between water level and fish yields in the Danube. The mechanism was based on the extensive flood plain that characterizes certain rivers like the Danube in contrast to the reduced flood plains found along most man-modified, temperate-region rivers. On such rivers, flood plain lakes contribute greatly to river fisheries by serving as nursery areas for many species. During years of long-lasting, high water levels, the conditions for fish reproduction tend to improve, and at the same time the flood plain lakes become a temporary refuge for fish carried in from adjacent river sections and carried downstream with the high flows. With more fish and easier accessibility to fishermen, fish yields are apt to improve.

Holcik and Bastl (1977) concluded that useful fish catch forecasts could be derived from single hydrological parameters. They cautioned, however, that their correlations should be of particular usefulness in rivers with extensive flood plains. Furthermore, the methods of prediction should be accompanied by information on biological population parameters, particularly when predictions for individual species are desired.

The relationship between fish catch and certain hydrological factors also has been studied in African flood plain rivers. Welcomme and Hagborg (1977) developed a model that described the manner in which fisheries in certain rivers were influenced by several aspects of the annual flood cycle. Fish catches were dependent on both the extent of

flooding at high water and the amount of water in the river's flood plain system during low water. Fish number and weight were compared with the flooding intensity, and the total number of fish surviving until the following year were more dependent on the low water regime. A negative log-log relationship was detected between catch and the ratio of maximum area flooded to minimum area of water remaining in the system. Welcomme and Hagborg suggested that this relationship of catch-to-flood ratio could form the basis of a general index for evaluating annual differences within one flood plain system and among several systems.

In addition to the results of this model, actual fish catch data for certain African flood plain rivers were shown to be predictable from river length: catch = $(\text{length})^2/300$ (Welcomme, 1976). This relationship may be adaptable for estimating fish catch sizes in certain U.S. rivers, but additional study is required. The significance of river length as a predictive factor in U.S. rivers has not been established.

4. Factor Selection

It is necessary to systematically select the key physical factors to be used in estimating the fish catch size regression analysis method developed for use by EPA. Two promising approaches for selecting key variables are factor analysis and stepwise regression analysis.

Several workers have used factor analysis to describe species associations of fish in rivers in the United States and Canada (Moreau and Legendre, 1979; Eschelle and Schnell, 1976). Moreau and Legendre sampled the fish at 163 relatively homogeneous stations in three northern rivers of Quebec. Physical similarity among the 163 stations was analyzed using depth, current velocity, water transparency, bottom type, and abundance of aquatic vegetation as the discrimination variables. Six habitat types were established using complete linkage clustering of a similarity matrix. Multiple discriminant analysis among the six habitat types was computed using abundances of the 18 fish species identified in the study, and the first two discriminant functions accounted for 88

percent of the variance among groups. The first function discriminated among stations by means of water transparency with the discriminating species being the sucker (Catostomus catostomus). The second function discriminated among stations on the basis of interaction between current velocity and vegetation abundance with a group of three fish being the discriminating species. The authors concluded that community structural changes arising from predictable physical alterations to the environment may be predicted from some relatively sophisticated technique such as their own.

Eschelle and Schnell (1976) established species associations among 48 species of fish in Oklahoma's Kiamichi River, using factor analysis of abundance data for 131 collecting localities. Their approach differed from Moreau and Legendre (1979) in that it involved calculating Pearson product-movement correlations between each pair of 48 species and establishing six principal axes (factors). Each factor represents several species that were positively associated with each other. In general, two parameters (competitive interaction and habitat preference) were reported to account for the observed patterns of species distribution in the Kiamichi River.

Perhaps the simplest approach to selecting the physical factors that would be useful in predicting fish catch sizes involves stepwise regression analysis. Various statistical analyses packages, such as SAS (SAS Institute, Inc., 1979), can be readily used to perform stepwise regressional analysis. The value of stepwise regression analysis is that it permits systematic evaluation of the importance of several independent variables (e.g., temperature, dissolved solids, flood height). The percentages of the total variance explained can be compared for a series of multiple regressions that are constructed by adding variables, one at a time, to the regression. With each variable added, the percentage of total variance explained will increase, and the researcher must weigh the costs and benefits of increasing the number of variables to be used in the regression.

E. FISH CATCH SIZE ESTIMATION IN MARINE WATERS

In contrast with the paucity of applicable information found on fish catch size estimation in free-flowing rivers, much information was found for estimating commercial coastal marine fish catch sizes using relatively simple environmental regressions, correlations, or indices. The resulting analyses have usually indicated that the key factor explaining fish catch size was a climatological parameter, often water temperature. Unfortunately, the database for estimating fish catch sizes for marine sport fisheries is much more limited than for commercial fisheries, and both data sources should be considered to evaluate total catch. Particularly valuable data in the development of future total catch estimates are the existing marine catch records available from various State and Federal agencies (e.g., California Department of Fish and Game, U.S. Department of Commerce). Marine sport catch estimates for a relatively few species have been reported for selected waters (see Table 4).

The discussion of the literature findings on fish catch size estimation in marine waters has been broken down into sections on correlation analyses, marine landings statistics, and recreational data.

1. Correlation Analyses

Many studies of marine fish and shellfish indicate that some relationships exist between environmental factors and selected characteristics of fish populations. Environmental factors such as temperature, salinity, oxygen, currents, upwelling, river discharge, general turbulence, atmospheric pressure, rainfall, and chlorophyll have been correlated with fish population characteristics. The characteristics of fish populations most often related to one of these environmental factors include: stock abundance, yield/catch, fish aggregations, population distribution, and spawning. The available data are usually derived from commercial fishing as well as some scientific expeditions. Predictive correlative relationships between environmental factors and sport fisheries were not found in the literature.

Twenty studies showing a correlation between the catch of some marine species and an environmental factor are summarized in Table 6. Correlation data are presented for more than 40 commercial species. (Fish identifications given in the studies were not always complete to the species level; hence, the approximate number). For many of the species, the catch reflected a change in some environmental factor without any lag time. For other species, lag times of up to 18 years were reported. Only four of the studies dealt with more than one species, and only two studies reported the analysis of more than one environmental factor. Thirteen of the 18 studies correlated catches with some measure of water temperature. The most frequently reported factor was the annual mean surface temperature, which was reported by Dow (1979) to correlate with fish catches of 34 species. Bottom temperature was correlated with catches of some demersal species (e.g., lobster). Temperature gradients were also correlated with some species yields.

Dow (1979) discussed the importance of surface sea temperature as an indicator of fluctuations in the annual catches (landings) of marine fish and invertebrates. He presented data on landings of 34 commercially important species and mean annual sea temperature of Boothbay Harbor, Maine. A particularly good example was the annual catch of lobster (Homarus americanus) (from 1939 to 1970), which was positively correlated ($r = 0.781$) with the sea temperatures of 5 to 7 years earlier. Positive correlations between temperature and annual landings at Boothbay Harbor were reported for 56 percent of the species; the other 44 percent were negatively correlated. Seven of the fish and eight of the invertebrate species showed a lag time in response to temperature; the lag times ranged from 2 to 18 years. Fourteen of the fish and five of the invertebrate species showed no lag time.

Sea scallop (Placopecten magellanicus) landings at Boothbay Harbor between the years 1905 and 1977 were negatively correlated ($r = -0.526$) with temperatures measured 7 to 8 years before (Dow, 1979). A similar lagged correlation was reported for surface temperature and scallop landings near Digby, Nova Scotia, between 1921 and 1971 (Caddy, 1979).

Table 6. Selected Studies Identifying the Relationship Between Environmental Factors and Fish Catch Estimation in Marine Waters

Factor	Species	Region	Comment	Reference
Water temperature (bottom)	Lobster	North Atlantic Coast (US)	Lobster catch (tons) correlated with bottom temperature at several stations; catch predicted from winter temperature of previous year and mean water temperature of 6-8 years.	Flowers and Saila (1972)
Water temperature (at 150-200 m)	Bottom fish	Barents Sea (West Spitzbergen)	Water temperature in a study area predicted catch 2-3 years before.	Konstantinov and Swetlov (1974)
Water temperature (surface)	Commercial (34)	Maine (US)	Boothbay Harbor (Maine) sea surface temperature predicted landings at Maine ports of 34 species with a lag time ranging from 0 to 18 years (r values given but not regressions).	Dow (1979)
Water temperature (surface)	Shrimp	World	Worldwide regression showed greater r than regression for local region.	Turner (1977)
Water temperature (surface)	Scallop	Bay of Fundy (Canada)	Catch was lag correlated with temperature and possibly also with long-period tidal oscillations.	Caddy (1979)
Water temperature (several depths)	Cod, haddock, flounder, menhaden, others	North Atlantic Coast (US)	Water temperature at several stations predicted fish catch (r = 0.77-0.92); predicted catches for different species had lag times of up to 7 years.	Sutcliffe et al. (1977)

Table 6. Selected Studies Identifying the Relationship Between Environmental Factors and Fish Catch Estimation in Marine Waters (Continued)

Factor	Species	Region	Comment	Reference
Water temperature (at 0-10 m)	Herring	Sea of Okhotsk (USSR)	Water temperature (at 0-10 m) in the study area indicated the best catches during everyday fishing operations; if temperature is 7.5-10.5° C, then catch is >200 kg/net; if <4° C or >13° C, no catch (r = 0.83).	Chernyavskiy (1970)
Water temperature (at 100 m)	Mackerel	Gulf of Mexico (Mexico)	Tons caught per hour inversely correlated with water temperature at 100 m; predicted minimum catch 1 month in advance; temperature indicates upwelling; data based on fishing at one station.	Gonzalez (1975)
Water temperature (at 0-200 m)	Several commercial	North Atlantic (unspecified region)	Average annual temperature over large area for predicting fish reproduction (not catch).	Bogdanov et al. (1975)
Water temperature	Herring	Sea of Okhotsk (USSR)	Predicted formation of schools that are susceptible to purse seining (r = 0.73).	Elkin (1973)
Water temperature (at 0-500 m)	Cod	Barents Sea (West Spitzbergen)	Water temperature (at 0-500 m) predicted fish distribution (r = 0.83) in the study area up to 6 months before trawling; temperature affects migration.	Konstantinov (1973)
Water temperature and river discharge	Sprat	Black Sea (USSR)	Water temperature and Dneiper River discharge predicted catch size.	Yuryev and Starushenko (1974)

Table 6. Selected Studies Identifying the Relationship Between Environmental Factors and Fish Catch Estimation in Marine Waters (Continued)

Factor	Species	Region	Comment	Reference
Water temperature and ice cover	Herring	Sea of Okhotsk (USSR)	Water temperature and ice cover predicted herring distribution during spawning.	Tyurnin (1973)
Upwelling	Crab	Pacific Coast (US)	Crab catch related to upwelling, plankton tows, and possibly temperature.	Botsford and Wickham (1975)
Current patterns	Many commercial	Japan Seas	Patterns of three Japanese currents predicted commercial catches of many fish species.	Uda (1974)
Atmospheric pressure	Sardine	West Indian Ocean	Atmospheric pressure differences between Cochin and Bombay, India, predicted the trend of the fishing season ($r = 0.84$).	Murty and Edelman (1971)
Mean rainfall	Sardine	West Indian Ocean	Mean daily rainfall for 2-week periods (June to August) indicated about 2 months in advance the success of the commercial fishery for juveniles.	Antony Raja (1974)
Oxygen (bottom)	Norway lobster	Norway	Good negative correlation between catch per hour and mean oxygen content at bottom.	Bagge and Munch-Petersen (1979)

In one of the more comprehensive studies relating fish catches to environmental factors, Sutcliffe et al. (1977) demonstrated that catches of 10 out of 17 commercial marine species of fish and shellfish from the Gulf of Maine were significantly correlated with sea temperatures at St. Andrews, New Brunswick or Boothbay Harbor, Maine. Annual catch data for each species were first correlated with mean monthly temperatures of the year in which the fish were caught. Correlations were then carried out with monthly temperature data from the year before the catch (a 12-month lag), with the process iteratively repeated for several previous years until a satisfactory correlation coefficient was obtained. Table 7 gives correlation coefficients (r), levels of significance, years of the catch statistics, and lag times for eight of the species. Catch statistics for the eight species were available for at least 39 years. Lag times for the eight species ranged from 1 to 7 years (and ranged from 1 to 11 years for all 17 species analyzed). The differences in lag times between St. Andrews and Boothbay Harbor were reportedly not significant. The authors noted the similarity between lag times and mean age at which each species could be commercially caught. This indicates that the effect of temperature is most important during the first year of life. The correlation coefficients given in Table 7 indicate the highest monthly coefficient for each species and are in general greater than 0.77. Determining the reasons for the positive or negative nature of the correlation would require additional information on species ecology and life history. For example, the authors suggested the negative correlation for the soft-shell clam was due to the increased abundance of a predaceous crab in warm years. Furthermore, of the seven finfish species that showed a negative correlation coefficient, six of the species were near their southern limits of commercial importance.

Another correlation technique, the Box-Jenkins approach, has been used recently to predict fisheries dynamics (Mendelssohn, 1981). This approach is especially useful for estimating the presence of autocorrelated errors. The approach was used in a 12-month forecast for the Hawaiian skipjack tuna industry based on landings data from 1964 to 1978.

Table 7. The Relationship Between Sea Temperature and Commercial Catches of Selected Species at St. Andrews, New Brunswick (SA), and Boothbay Harbor, Maine (BH)[a]

Species	Years	Lag Time (years)	Correlation Coefficient (r)	Level of Significance
Alewife (*Clupea harengus*)	1928-71 (SA)	6	0.850	0.001-0.01
	1928-71 (BH)	5	0.841	0.01
Butterfish (*Peprilus triacanthus*)	1928-71 (SA)	4	0.735	0.02-0.05
	1928-71 (BH)	5	0.786	0.02
Atlantic cod (*Gadus morhua*)	1925-73 (SA)	4	-0.850	0.01-0.02
	1914-73 (BH)	4	-0.668	0.05
Menhaden (*Brevoortia tyrannus*)	1929-71 (SA)	3	0.872	0.01
	1929-71 (BH)	2	0.881	0.001-0.01
Yellowtail (*Limanda ferruginea*)	1935-74 (SA)	2	-0.792	0.007
	1935-74 (BH)	1	-0.797	0.007
Hard clam (*Mercenaria mercenaria*)	1928-71 (SA)	2	0.805	0.02-0.05
	1928-71 (BH)	3	0.744	0.05
Soft clam (*Mya arenaria*)	1928-71 (SA)	7	-0.798	0.05-0.10
	1928-71 (BH)	7	-0.886	0.02
Sea scallop (*Placopecten magellanicus*)	1928-71 (SA)	6	0.796	0.06
	1928-71 (BH)	5	0.885	0.02

[a]Source: Sutcliffe et al. (1977).

Box-Jenkins models (Box and Jenkins, 1976) are autoregressive-integrated, moving-average models. As a group, they are linear, stochastic models that are based on a stationary time series. Mendelssohn identified, estimated, and checked a series of models using the historical catch data (1964-78) for skipjack tuna, which had been traditionally considered to be too variable to forecast monthly. The model successfully forecasted: (1) the total monthly catches for 1979 (with an error of 15 percent); (2) the low, flat catch during summer; and (3) most of the turning points in the observed landings data.

Mendelssohn (1981) postulated that several problems in the model predictions were due to economic and fisherman behavioral factors rather than to characteristics of the fish populations. The overall success of the approach was attributed to the ability of the Box-Jenkins model to provide the maximum likelihood estimators that would not be biased when data variables are seasonal, autocorrelated, and lagged on themselves. Water temperature and salinity data added very little to the predictions and were dropped in the final model. Mendelssohn, however, pointed out that the ability to incorporate various environmental factors into the model was one potential advantage of his stochastic procedure.

Numerous other marine fishery studies have suggested possible correlations between environmental factors and characteristics of fish populations (see Table 8). In fact, most of the literature on the influence of environmental factors is concerned with fish distribution, the location of fish aggregations, the time of arrival at spawning grounds, natural fluctuations of fish stocks, various yield parameters, and the prediction of fishing conditions. As can be seen from the studies listed in Table 8, many edible species are shown to be related to at least one of the following eight factors: surface temperature (13 species), bottom temperature (5), temperature gradient (9), salinity (4), oxygen (3), currents (6), chlorophyll (2), and turbulence (2).

Table 8. The Relationship Between Environmental and Marine Fish Parameters

Factor	Related To	Species	Location	Reference
Surface temperature	Yield/catch	Tuna	Brazil	De Moraes (1967)
	Yield/catch	Mackerel	Yellow Sea (China)	Kondo (1969)
	Yield/catch	Mackerel	India	Noble (1972)
	Yield/catch	Sardine (oil)	India	Murty (1965)
	Yield/catch	Menhaden	Gulf of Mexico	Stone (1976)
	Yield/catch distribution	Yellowtail	Japan	Tanaka (1975)
	Yield/catch and fish distribution	Bonita	U.S. (West Coast)	Radovich (1963)
	Yield/catch and fish distribution	White marlin	Gulf of Mexico	Kemmerer et al. (1977)
	Yield/catch and fish aggregation	Striped marlin	California	Squire (1974)
	Fish distribution and aggregation	Menhaden	Gulf of Mexico	Gallaway and Strawn (1974)
	Fish distribution and aggregation	Anchoveta	Peru	Jordan (1971)
	Fish distribution and aggregation	Salmon	Japan	Tanaka (1965)
	Fish distribution	Tuna	Guinea	Stretta (1976)
	Fish distribution	Herring	Sea of Okhotsk	Takahashi (1976)
	Fish aggregation	Mackerel	Korea	Gong et al. (1972)
	Fish aggregation	Coho salmon	U.S. (West Coast)	Wright et al. (1976)

Table 8. The Relationship Between Environmental and Marine Fish Parameters (Continued)

Factor	Related To	Species	Location	Reference
Bottom temperature	Fish distribution	Cod, haddock	Atlantic Ocean	Tatyankin (1972)
	Fish distribution and spawning	Plaice, haddock	New England	Colton (1972)
	Fish aggregation	Lobster, shrimp	New England	Dow (1969)
Temperature gradient	Yield/catch	Sardine (oil)	India	Murty (1965)
	Fish distribution	Albacore	U.S. (West Coast)	Laura and Lynn (1974)
	Fish distribution	Tuna	Pacific Ocean (Tropics)	Yamanaka (1969)
	Fish distribution	Cod, haddock	Atlantic Ocean	Tatyankin (1972)
	Fish distribution	Herring	Sea of Okhotsk	Takahashi (1976)
	Fish distribution and aggregation	Salmon	Japan	Tanaka (1965)
	Fish distribution and aggregation	Striped marlin	Baja, California	Hamamoto (1974)
Salinity	Fish distribution	Tuna	Chile, Peru	Sandoval (1971)
	Fish distribution	Tuna	Guinea	Stretta (1976)
	Fish distribution	Salmon	Canada (West Coast)	Favorite (1969a,b,c)
	Fish distribution	Herring	Sea of Okhotsk	Takahashi (1976)
	Fish aggregation	Skipjack tuna	Pacific Ocean	Barkley (1969)
	Fish aggregation	Tuna	Guinea	Voituriez et al. (1973)

Table 8. The Relationship Between Environmental and Marine Fish Parameters (Continued)

Factor	Related To	Species	Location	Reference
Oxygen	Yield/catch	Mackerel	India	Noble (1972)
	Fish distribution	Tuna	Chile, Peru	Sandoval (1971)
	Fish distribution	Tuna	Guinea	Stretta (1976)
	Fish distribution and aggregation	Striped marlin	Baja, California	Hanamoto (1974)
Currents	Yield/catch	Tuna	Brazil	De Moraes (1967)
	Yield/catch	Sardine (oil)	India	Murty (1965)
	Fish distribution	Tuna	Chile; Peru	Sandoval (1971)
	Fish distribution	Salmon	Canada (West Coast)	Favorite (1969a,b,c)
	Fish distribution and aggregation	Skipjack tuna	Hawaii	Seckel (1972)
	Fish distribution and aggregation	Salmon	Japan	Tanaka (1965)
Chlorophyll	Yield/catch and fish distribution	White marlin	Gulf of Mexico	Kemmerer et al. (1977)
	Yield/catch and fish distribution	Menhaden	Gulf of Mexico	Kemmerer et al. (1977)
Turbulence	Yield/catch	Brown shrimp	Gulf of Mexico	Linder and Bailey (1969)
	Fish aggregation	Menhaden	Gulf of Mexico	Needham (1975)

The correlation approach, however, has generated much controversy in the scientific literature. Holcik and Bastl (1977) and Nikolskii (1969) stated contrasting opinions on the usefulness of physical and hydrological parameters to predict fish yields. Holcik and Bastl suggested the utility of their correlations for predicting total yields from flood plain rivers, whereas Nikolskii cautioned that marine cod fisheries had suffered from bad predictions. Both opinions, however, were offered cautiously. Nikolskii recognized the importance of a hydrological background in long-term forecasts but pointed out that serious problems for fishing fleets have resulted from the overreliance on a single parameter. He cited a case where temperature was used to predict fishing effort, season, and location for the Arctic Norwegian cod. Although he gave no actual numbers, Nikolskii reported that the predictions failed, with disastrous economic consequences. The apparent simplicity of the forecasting technique created an impression that information on the state of the fish population was not necessary. The levels of accuracy required to predict fishing fleet success, however, may be far higher than needed for estimating general levels of stock abundance.

Holcik and Bastl (1977) concluded that their data did show that useful fish catch forecasts could be derived from single hydrological parameters. They also cautioned, however, that their correlations should not be considered generally valid, but rather of particular usefulness in rivers with extensive flood plains. Furthermore, the methods of prediction should be accompanied by information on biological population parameters, particularly when predictions for individual species are desired.

As a general precaution, correlation results should be interpreted with care in light of general implications and the limits of the statistical relationship. The correlation coefficient, which is used to measure the degree of association between two variables and to demonstrate whether the association is higher than expected by chance,

indicates a relationship that is not necessarily directly causal. For example, a high correlation may indicate that: (1) one variable directly influences the other, (2) a third variable influences the other two variables, or (3) there is some more or less complex alternative. High correlation coefficients, however, may suggest profitable areas for additional research.

2. Marine Landings Statistics

The National Marine Fisheries Service (NMFS) of the U.S. Department of Commerce publishes annual summaries of commercial and recreational marine fish catches for the United States. These catch data are classified by species, regions, States, and even by port for some statistics (U.S. Department of Commerce, 1982). Most of the published data cover geographic areas too broad to be very useful in local fish catch assessments, but data are available in the NMFS computer files that may be directly usable. For the Atlantic and gulf coasts, monthly data (since 1970) are available by species and county for 15 States (Maine, Massachusetts, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina, Alabama, Mississippi, Louisiana, and Texas). For the West Coast, monthly data by species are available for fewer than 20 statistical areas within four States (Alaska, Washington, Oregon, and California).

Most States publish their own fisheries data regularly and some, like California, provide the data used in the NMFS estimates. The California Department of Fish and Game has published data on other categories of fish catches for more than 50 years. The statistics are based on a system by which commercial fishermen, fish dealers, processors, and operators of sport fishing party boats send duplicates of their records to the Department of Fish and Game. Of particular interest are data for monthly catches (commercial, party boat, and other recreational) summarized by species for seven statistical areas in California (McAllister, 1975). Access to State records of raw data for these summaries should provide a useful historical perspective as well as data for regression analyses.

3. Recreational Data

Some of the difficulties of obtaining recreational fish catch data have been addressed. Obtaining good data from party boat groups seems to be less difficult than obtaining data for individual anglers' groups. (Young, 1969; Huntsman et al., 1978).

Huntsman and coworkers (1978) described two methods for measuring daily catches in party boats (also called head boats). They obtained data from commercial boats taking anglers who paid for a half or full day of fishing on the Outer Continental Shelf off of North and South Carolina. The major problem reported in estimating the head boat catches by individual species was generally related to the lack of sufficient numbers of trained individuals for accurately counting the catch. Huntsman and his coworkers compared logbook estimates (a crewmember on each vessel keeps a record) with a creel survey estimate (a creel clerk examines as many stringers as possible for anglers as they leave the boats). Although they did not know the actual catches (and therefore could not tell which technique was more accurate), the dockside creel census was judged to be less biased than the logbook census. The dockside census estimated catches to be between 47 percent and 87 percent (mean of 58 percent for all catches) of the catch reported by crewmembers in logbooks.

Logbook estimates, however, were recommended for several reasons. First, they offered extensive and relatively inexpensive coverage. The authors obtained records for about half of the head boat trips per season at a cost less than the cost for covering 3 percent of all trips by stringer. Logbooks also provided better information on unusual species, since the angler would often ask the crewmembers' help in identification.

Another promising source of recreational data is the NMFS, which is carrying out a long-term creel survey of individual anglers (U.S. Department of Commerce, 1979). B. G. Thompson, who is chief of the Resource Statistics Division of NMFS, reported (personal communication) that nearly 2,000 sites are being monitored along the coast between Maine and Texas, with several hundred being sampled daily. Although the data are not currently available, it is expected that these may contribute significantly to the problem of estimating marine fish catches by individual anglers.

IV. REGRESSION ANALYSIS WORK PLAN DEVELOPMENT

Regression analysis offers the most promising approach for estimating fish catch size in free-flowing rivers or nearshore marine areas. The objective of using this approach is to formulate a series of regressions that may be used to estimate or predict fish catch size for each of the major edible species (see Table 1). To formulate each regression, it is necessary to start with the appropriate historical fish catch records and matching environmental data for corresponding years. The steps required to obtain the best series of regressions are given in the work plan below.

A. HISTORICAL USE OF REGRESSION ANALYSIS

The regression analysis approach, or the analogous correlation approach, has been used with some success by many researchers to estimate fish catch size in numerous reservoirs, in some free-flowing rivers, and in many marine waters (see chapter III). The greatest success in using this approach has been achieved in concert with selected groups of large reservoirs. The works of Ryder et al. (1982) in Canada and Jenkins et al. (1971) in the United States are most prominent. Their research has demonstrated the usefulness of one or more particular factors (e.g., total dissolved solids, growing season duration, and reservoir depth and surface area) in estimating fish catch size.

Regression analysis has also been used successfully to indicate that the fish catch size of many marine species may be highly correlated with certain environmental factors. Researchers such as Dow (1979) and Sutcliffe et al. (1977) have published such regressions or correlations (see Table 6). Temperature, salinity, dissolved oxygen, and current pattern are among the most frequently cited physiocochemical parameters that correlate well with fish catch size.

In rivers, the regression analysis approach has been used much less frequently than in reservoirs or marine waters. A number of factors may contribute to this, but the most important is probably the relative unpredictability of certain physical, chemical, and biological aspects of many rivers. Another key factor is their susceptibility to pollution episodes, which may occur suddenly and leave no detectable trace other than the disappearance of biota. A third factor is that many streams are of little interest to fishermen. Regression analysis, however, has been successfully used to estimate fish catch size in certain large rivers with extensive flood plain fisheries (Holcik, 1979; Welcomme, 1976). Two of the parameters that have been found to correlate with river fish catch size are river length and river water level fluctuation.

B. REGRESSION ANALYSIS WORK PLAN

A four-step plan is proposed to demonstrate the usefulness of regression analysis for individually estimating fish catch size of the major edible species. The steps in the work plan include:

1. Establish priorities for selecting the order in which species will be studied and the environmental factors to be used in each regression analysis.

2. Obtain suitable fish catch and environmental data.

3. Summarize and analyze data using the Statistical Analysis System.

4. Adapt the regression analysis approach for estimating fish catch size by testing different combinations of fish catch and environmental data.

1. Establish priorities for selecting the order in which species will be studied and the environmental factors to be used in each regression analysis.

Since the objective of this work is to develop a series of regressions to estimate fish catch size for each of the major edible species (listed in Table 1), the first step involves selecting the order in which the regressions will be formulated. Two key elements in determining this order will be the availability of appropriate catch data and knowledge of the most important species to man; i.e., those species consumed in greatest amounts or those posing the greatest potential exposure hazards to man.

The inadequacy of the historical fish catch data for individual species may hamper the achievement of the work plan objective. The catch data that are available vary in quality and quantity for a number of reasons that include the economic significance of the species, the locations where the fish are found, and the relative importance of sport fishing to the total fishery.

It is also necessary to select the appropriate environmental factors that are to be used as independent variables in the regression analysis. Initial selection of these factors (e.g., temperature, salinity, water level) will be based on the scientific literature discussed in chapter III. The availability of adequate data will again be very important. A systematic effort should be carried out to establish which of the potentially large groups of environmental factors can best be used to estimate fish catch size. Stepwise regression analysis offers the best systematic approach for factor selection and is discussed in step 3.

2. Obtain suitable fish catch and environmental data.

Historical fish catch and environmental data for corresponding years must be translated into a form suitable for computerized regression analysis. Some of the data already exists in a computerized form as

tapes or disks. Computerized fish catch data for coastal States, individual counties, and key fishing ports are available from the NMFS, according to the Chief of Resource Statistics, B. G. Thompson. Computerized environmental data (physicochemical) for many localities in nearly all States, not just coastal, also are available from at least two major databases (i.e., STORET and WATSTORE). In general, however, fish catch data for rivers and marine systems are not expected to be comparable to environmental data in availability and quality, or in suitability, for computer analysis.

The regression analysis approach shows greater promise in marine waters than in free-flowing rivers because of the more extensive historical fish catch data that are available for marine systems. Commercial catch data have been compiled by many of the coastal States and by the NMFS for several decades for most of the edible fish and shellfish. Some of the States have kept detailed commercial records by township (e.g., Massachusetts and Maine). Most other States have records by county or by broader geographic region. A number of States have good sport catch records as well (e.g., California). However, sport catch records are generally much inferior to commercial catch records. The best available computerized fish catch records are from the NMFS and may be obtained on tape or disk. Computerized records from individual States are not currently available.

Where the suitable fish data can be obtained from the scientific literature, government reports, or State government files, these data should be entered into an appropriate computer-usable format for regression analysis.

Computerized historical records for many key environmental factors in both marine and river habitats are much better than such records for fish catch. Temperature, salinity, river discharge, water level, water chemistry, and other parameters have been compiled for many localities by various Federal and State agencies that include EPA, the National

Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (COE), the U.S. Geological Survey (USGS), and State water pollution agencies.

Much of this environmental information may be obtained from two major databases, STORET and WATSTORE. STORET is EPA's computerized database for the storage and retrieval of information relating to the quality of waterways in the United States. The data have been accumulated from the 1950's to the present and are derived from sources such as USGS, COE, U.S. Forest Service, Bureau of Land Management, FWS, and various State pollution control agencies. Hundreds of physical, chemical, and biological parameters are available from thousands of individual locations. The data may be retrieved in raw or summarized form on disk by State, county, river basin, or other designation. WATSTORE is a water data storage and retrieval system compiled by the National Water Data Exchange System of the USGS, which obtains data from 600 organizations that provide physical, chemical, and biological data from thousands of sites.

3. Summarize and analyze data using the Statistical Analysis System.

The Statistical Analysis System (SAS) provides a valuable package for effectively summarizing the fish catch and environmental data and for performing the regression analysis. A stepwise regression analysis is carried out using the SAS procedure known as PROC STEPWISE. This procedure systematically analyzes all of the combinations of environmental factors and yields a series of multiple regressions that indicate the relative contribution of different factor combinations in estimating fish catch size. Using MAX R, one of the five methods provided in the stepwise procedure, it is possible to obtain for each species the best one-variable model, two-variable model, and additional variable models. With each variable added, the percentage of total variance explained by the regression will increase, but it is necessary to carefully weigh the costs and benefits of increasing the number of

variables. Stepwise analysis, however, should prove to be particularly useful in the fish catch size estimation problem, since it is expected that for some species there may be a large group of potentially usable environmental factors.

As a part of this step, decisions about the necessity for various data manipulations should be explored. For example, regression analysis is a parametric technique requiring the data to be normally distributed. It may be that the raw data are not normally distributed, but a simple transformation will normalize the frequency distribution of the data. Log transformation and square root transformation are two techniques that are widely used and readily accomplished with SAS.

4. Adapt the regression analysis approach for estimating fish catch size by testing different combinations of fish catch and environmental data.

The final step involves establishing the generality of the regression analysis approach; that is, adapting its use for estimating catch sizes of the major edible species. The question that must be addressed is not simply how well the regression analysis approach works for a particular species in a single locality, but rather how well the approach works for the majority of species in the many localities in which they are found. In a method that parallels Ryder's (1982) approach for estimating fish catch size in reservoirs, a series of regressions should be developed for each marine and freshwater species on a subregional (e.g., a State), regional (e.g., several States), or even a national basis. Regressions derived on a subregional basis are expected to have correlation coefficients higher than regionally or nationally derived regressions. This step will also indicate to what extent it is possible to use the same factor(s) for a particular species in more than one locality. Each locality will have its own unique historical catch and environmental database, but it is expected that only one or a few

of the environmental factors will prove to be the best independent variables in most of the regressions. The particular regression formulation will probably vary a great deal from species to species and from site to site. It is the similarity of the regressions that will establish this method as a meaningful approach to estimating fish catch size.

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